

Express Mailing Label No.: ER211533068US

PATENT APPLICATION

Docket No.: 1500.2.9

IBM Docket No.: TUC920020127US1

**UNITED STATES PATENT APPLICATION**

of

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for

**RECORDING HEAD COMPENSATION FOR  
TAPE SHRINKAGE AND EXPANSION**

## **BACKGROUND OF THE INVENTION**

### **1. The Field of the Invention**

This invention relates to tape recording heads, and more particularly to tape recording heads configured to compensate for magnetic tape shrinkage and expansion.

### **2. The Relevant Art**

Magnetic recording has played an important role in the electronic age for permanently storing and retrieving data. Within the field of magnetic recording, few media technologies have been used as extensively as magnetic tape. Magnetic tape has been widely used to store music, video, as well as digital data processed by computers. However, as other types of magnetic media, such as hard drives, have become more economical and capable of storing larger quantities of data, reliance on magnetic tape for data storage has declined.

Part of this decline may be attributed to perceptions of lower reliability of tape, or to slower storage or retrieval of data therefrom. Reliability concerns originate in part from the fact that magnetic tape is prone to shrink and expand due to changes in environmental temperature, humidity, creep caused by tension on the tape, or creep caused by the tendency of an extruded material, such as tape, to return to a previous form.

Nevertheless, using tape for data storage still provides significant advantages, including its relatively low cost and large storage capacity. Very few other technologies offer the combined low cost and high capacity advantage of tape. While other technologies may offer various advantages with respect to tape in specific areas, overall, none of these technologies compare to tape in addressing customer needs for low cost and storage capacity.

As is customary with other storage mediums, significant effort is directed to storing larger quantities of data on smaller areas of the medium (e.g. increasing storage density). Moreover, additional effort is directed to storing and retrieving the data faster and more efficiently. As data is stored on tape in increased density, one issue becomes reliably writing

1 and retrieving data stored on smaller and smaller areas of the tape.

2 For example, in order to accurately store and retrieve data from tape, data recording  
3 and reading heads need to be accurately positioned with respect to the tape surface. The  
4 complexity of this task is compounded by possible changes in a tape's dimensions. Even  
5 slight amounts of tape distortion may make the retrieval of written information difficult if not  
6 impossible.

7 Problems incurred by the dimensional instability of tape and its limitations with  
8 respect to track density in multi-read element systems is well known in the art. One  
9 proposed solution is to place the elements of a multi-element head closer together. However,  
10 existing heads are as close together as current technology allows.

11 Another approach is to skew a recording head with respect to the magnetic tape such  
12 that rotation of the head varies the effective span of the head over tracks on the tape.  
13 However, skewing the head causes problems when reading the data. Moreover, due to the  
14 "cosine" characteristics of skewing the head, a relatively large skew is required to  
15 significantly affect the span of the head over the tape.

16 Thus, in accordance with the previously stated concerns, apparatus and methods are  
17 needed to more accurately store and retrieve data from magnetic tape using recording and  
18 reading heads. What is further needed are apparatus and method to accurately store and  
19 retrieve data while compensating for expansion or shrinkage of tape due to humidity,  
20 temperature, or creep.

21 Accordingly, it would be an advance in the art to provide a recording head that could  
22 accurately store and retrieve data on tape even when the tape has changed dimensions due to  
23 humidity, temperature, creep, or other causes.

## SUMMARY OF THE INVENTION

Accordingly, an apparatus in accordance with the present invention provides a recording head to simultaneously read or write data to and from a plurality of tracks on magnetic tape, while compensating for shrinkage or expansion caused by moisture, temperature, creep caused by tension in the tape, creep caused by dimensional instability of the tape, as well as other causes. In one embodiment, a recording head in accordance with the invention includes a leading module and a trailing module. A leading module refers to a module that initially reads or writes data to or from the tape as it is translated past the head. A trailing module refers to a module that reads or writes data to or from the tape after it has passed the leading module.

In certain embodiments, each of the leading and trailing modules includes a plurality of read and write elements located linearly or substantially linearly along the lengths thereof. "Read elements" refer to components or devices that are effective to read data from a magnetic tape. Likewise, "write elements" refer to components or devices that are effective to write data to magnetic tape.

In certain embodiments, each of the leading and trailing modules include read and write elements located in a "piggyback" configuration, wherein corresponding read and write elements are located on the same module and are substantially aligned with one another. In another embodiment, each of the leading and trailing modules include read and write elements that are "interleaved," meaning that read and write elements are placed at intervals along the length of each of the modules, and in an alternating manner.

In selected embodiments, such as in a "piggyback" configuration, the leading and trailing modules are virtually identical modules having read and write elements that mirror the other's read and write elements. In other embodiments, such as in an "interleaved" configuration, the leading and trailing modules have read and write elements that oppose one another. That is, a read element located on the trailing module is substantially aligned with a write element on the leading module, and vice versa.

1 In order to accommodate fluctuation in tape dimensions due to expansion or  
2 shrinkage, the leading and trailing modules are offset with respect to one another. That  
3 is, a leading module is offset, in a direction parallel to the length of the leading module,  
4 from the trailing module. By offsetting one module with respect to the other, selected  
5 read and write elements from one module more closely align with certain tracks of an  
6 expanded or shrunk tape, while other read and write elements from the other module  
7 more closely align with other tracks on the tape.

8 In selected embodiments, the trailing module is fixed with respect to the leading  
9 module. In other embodiments, the trailing module is rigidly attached to the trailing  
10 module using glue, welding, or other attachment means.

11 In certain embodiments, read elements from a trailing module are used to read and  
12 verify data that is written by write elements on a leading module. Likewise, in the reverse  
13 direction, the leading and trailing modules are interchanged and again read elements from  
14 the new trailing module are used to read and verify data that is written by write elements  
15 on a new leading module. By using read elements on one module to verify data written by  
16 elements on the other module, interference between read and write elements on the same  
17 module may be avoided.

18 The leading and trailing modules also include servo readers to read servo bands on  
19 the magnetic tape. The servo readers align the recording head with the magnetic tape  
20 such that read and write elements are aligned with selected data tracks. In cases where a  
21 magnetic tape has expanded or shrunk, the servo readers may serve to measure the width  
22 of the tape in order to make necessary adjustments to the position of the recording head.

23 Misalignment is due to differences in the width of the tape from the time it is  
24 written to the time it is read. At the time data is written, two servo readers on either side  
25 of the data band may measure the width of the tape. This width may be recorded along  
26 with data onto the tape. When the tape is read, the difference in tape width since data was  
27 last written may be calculated. This calculation may be used to select read and write

1 elements on the leading and trailing modules that are most aligned with data tracks on the  
2 tape. In a "read back" mode, read elements from either the leading or trailing modules  
3 can be used without interference with write elements because the trailing module is not  
4 needed to verify data that was just written.

5 In selected embodiments, if it is determined that a tape is substantially unaltered  
6 (e.g. not expanded or shrunk), all of the read elements from a single module (e.g. either  
7 the leading or trailing module) are used to read data from the tape. If it is determined that  
8 the tape has expanded, a portion of the read elements from one module are used to read  
9 certain data tracks, while a portion of the read elements from the other module are used to  
10 read other data tracks. Likewise, if it is determined that the tape is shrunk since data was  
11 last written, a portion of the read elements from one module are used to read certain data  
12 tracks, while a portion of the read elements from the other module are used to read other  
13 data tracks.

14 In certain embodiments, a control module is operably connected to the servo  
15 readers and the read and write elements to effectively position the elements over the data  
16 tracks, and to determine which read and write elements of each module will be used to  
17 read and write data. In selected embodiments, each module is effectively divided up into  
18 halves, each half including half of the read and write elements of the respective module.

19 The recording head may be characterized by three modes: a first mode  
20 characterized by half of the leading module and half of the trailing module to read data  
21 from expanded tape; a second mode characterized by the other half of the leading module  
22 and the other half of the trailing module to read data from a shrunken tape; and halves  
23 from the same module (trailing or leading) when tape is substantially unaltered.

24 In another aspect of the present invention, a method for simultaneously reading  
25 and writing data to and from a plurality of tracks on magnetic tape, while compensating  
26 for shrinkage or expansion of the magnetic tape, includes providing a leading and trailing  
27 module comprising a plurality of read and write elements located at spaced intervals

1 along the lengths thereof. The method further includes offsetting the trailing module with  
2 respect to the leading module to compensate for the expansion or shrinkage.

3 If the tape has expanded or shrunk, a method in accordance with the invention  
4 includes substantially aligning selected read and write elements from the leading module  
5 with selected data tracks on the tape, and substantially aligning selected read and write  
6 elements from the trailing module with other selected data tracks on the tape. In certain  
7 embodiments, half of trailing module and half of the leading module is used to read data  
8 tracks on a tape in an expanded or shrunken state.

9 The method may further include fixing the trailing module with respect to the  
10 leading module. In certain embodiments, the method includes rigidly attaching the  
11 trailing module to the leading module.

12 In another aspect of the present invention, a system for simultaneously reading  
13 and writing data to and from a plurality of tracks on magnetic tape, while compensating  
14 for shrinkage or expansion of the magnetic tape, includes a magnetic medium, such as  
15 magnetic tape, containing a plurality of data tracks located at spaced intervals thereon.  
16 The system further includes a data storage device for storing data on the magnetic tape.  
17 The data storage device includes a recording head for reading and writing to and from the  
18 data tracks on the tape.

19 The recording head includes a leading module comprising a plurality of read or  
20 write elements located at spaced intervals along the length of the leading module, and a  
21 trailing module comprising a plurality of read or write elements located at spaced  
22 intervals along the length thereof. The trailing module is offset with respect to the  
23 leading module in order to align selected read or write elements from the trailing module  
24 with selected data tracks on the magnetic tape, and to align selected read or write  
25 elements from the leading module with other selected data tracks on the magnetic tape.  
26  
27

## **BRIEF DESCRIPTION OF THE DRAWINGS**

The foregoing and other features of the present invention will become more fully apparent from the following description, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only typical embodiments in accordance with the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

Figure 1A is a schematic block diagram illustrating one embodiment of a data storage device containing a recording head used to write or read data to or from a magnetic medium, such as magnetic tape;

Figure 1B is a perspective view illustrating one embodiment of a recording head configured to read or write multiple data tracks onto a magnetic medium;

Figure 2 is a schematic block diagram illustrating one embodiment of a recording head having a leading and trailing module, each module including servo readers for positioning the recording head with respect to a magnetic tape, and various read and write elements to read and write data to the magnetic tape;

Figure 3A is a schematic block diagram illustrating one embodiment of leading and trailing modules having read and write elements in a "piggyback" configuration, and an exploded view of the alignment of read and write elements when the leading and trailing modules are offset with respect to one another;

Figure 3B is a schematic block diagram illustrating one embodiment of leading and trailing modules having read and write elements in an "interleaved" configuration, and an exploded view of the alignment of read and write elements when the leading and trailing modules are offset with respect to one another;

Figure 4 is a schematic block diagram illustrating one embodiment of offset leading and trailing modules used to read and write data to a magnetic tape in a substantially unaltered state;



1           Figure 5 is a schematic block diagram illustrating one embodiment of offset leading  
2 and trailing modules used to read from a magnetic tape in a substantially expanded state;

3           Figure 6 is a schematic block diagram illustrating one example of a tape system, such  
4 as an LTO (Linear Tape-Open) system, in which a recording head in accordance with the  
5 invention may be used;

6           Figure 7 is a schematic block diagram illustrating one embodiment of various modes  
7 that may be used to read data tracks on unaltered, expanded, or shrunken tape;

8           Figure 8A is a schematic block diagram illustrating one embodiment of a control  
9 module used to control read and write elements from the leading and trailing modules;

10          Figure 8B is a schematic block diagram illustrating one embodiment of a control  
11 module used to control read and write elements from the leading and trailing modules  
12 individually; and

13          Figure 9 is a schematic block diagram illustrating one embodiment of the alignment  
14 of the read elements with data tracks on an expanded tape.

## DETAILED DESCRIPTION OF THE INVENTION

Various functional units described in this specification have been labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom VLSI circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

Modules may also be implemented in software for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions that may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module need not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

Indeed, a module of executable code could be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network.

Referring to Figure 1A, a data storage device 10 used to store data on magnetic tape 12, or some other medium 12, typically uses one or more recording heads 14. In certain embodiments, a recording head 14 functions by creating a magnetic field 16 or magnetic flux 16 that magnetizes a magnetic material on the surface of the tape 12, such as iron ferrite or

1 some other ferromagnetic material. Ferromagnetic materials refer to elements or materials  
2 that, when exposed to a magnetic field, become magnetized themselves. By selectively  
3 magnetizing portions of the tape 12, data is encoded or stored. Moreover, by re-exposing the  
4 tape to a magnetic field 16, data may be rewritten with other data, or erased entirely. Since  
5 portions of the tape 12 become magnetized when exposed to a magnetic field, a head 14 may  
6 also be used to read data from the tape 12 when translated over the surface thereof.

7 For example, a ferrite core recording head 14 may be used to illustrate the function of  
8 a recording head 14. Various types of recording heads 14 may be used in accordance with  
9 the present invention, and a ferrite core recording head 14 is simply presented by way of  
10 example and not limitation. One or more terminals 18a, 18b receive a data signal carrying  
11 data for storage on the tape 12. The terminals 18 are connected to a wire 19 or conductor 19  
12 coiled around a ferrite core 20.

13 Current is transmitted through the coil 19, thereby creating a magnetic flux traveling  
14 through the coil 19. This flux travels through the iron core 20 and is retained therein until it  
15 reaches a gap 22 in the core 20. As magnetic flux reaches the gap 22, the flux creates a  
16 fringe pattern 16 as it spans the gap 22. The fringe pattern 16 is used to magnetize  
17 ferromagnetic material on the surface of the tape 12. As previously stated, there are very  
18 many types of recording heads 14 available, all within the scope of the present invention, and  
19 the illustrated example is simply presented by way of example.

20 Referring to Figure 1B, in selected embodiments, a recording head 14 is a multi-track  
21 recording head 14. That is, a recording head 14 may read or write several tracks of data to a  
22 tape 12 simultaneously. For example, a multi-track recording head 14 includes multiple read  
23 or write elements 24a-d. Each of the read and write elements 24a-d may be operably  
24 connected to separate terminals 18 (not shown), may be operated independently, and may  
25 read or write distinct or redundant information to the tape 12.

26 Referring to Figure 2, a multi-track recording head 14 in accordance with the  
27 invention includes a leading module 26 and a trailing module 28. For example if a tape 12

1 moves in a direction 30, a leading module 26 is defined as the first module 26 to read or  
2 write to the tape 12. Likewise, the trailing module 28 reads or writes to the tape 12 after the  
3 leading module 26.

4 The tape 12 includes various tracks containing data and other tracks for properly  
5 positioning the head 14 with respect to the tape 12. For example, the tape 12 includes a  
6 plurality of data tracks 32a-h to store data. Likewise, the tape 12 may include servo tracks  
7 34a, 34b containing data used for accurately positioning the recording head 14 with respect  
8 to the tape 12 and for measuring shrinkage or expansion of the tape 12.

9 Each of the leading and trailing modules 26, 28 includes a plurality of read elements  
10 36a-d and a plurality of write elements 38a-d. The read and write elements 36, 38 are used to  
11 read and write data to and from the data tracks 32. The read elements 36 are used to read  
12 data that is stored on the tape 12, or are also used to immediately verify data that has been  
13 written to the tape 12 by the write elements 38. In certain embodiments, the write elements  
14 38 are wider than the read elements 36. This helps ensure that a written track 32 is wide  
15 enough for a read element 36 to read the track 32 without reading data in adjacent tracks 32,  
16 thereby corrupting data or incurring errors. In selected embodiments, the write elements 38  
17 are wider than the read elements 36 and are offset somewhat from centerline to centerline.  
18 This is typical of "shingled" writing used to provide compatibility with previous tape  
19 generations.

20 In certain embodiments, read elements 36 of the trailing module 28 verify data  
21 written by write elements 38 of the leading module 26. Likewise, if the tape 12 is reversed in  
22 direction (opposite to direction 30), then the trailing module 28 becomes the leading module  
23 26, and the leading module 26 becomes the trailing module 28. Thus, in this scenario, the  
24 read elements on the module 26 would be used to verify data written by write elements 38 on  
25 the other module 28.

26 The recording head 14 also includes servo readers 40a-d. The servo readers 40a-d are  
27 used to align the recording head 14 with respect to the tape 12 by detecting data or

1 information contained within the servo tracks 34a, 34b. In certain embodiments, the servo  
2 readers 40 are substantially aligned with the center of the servo tracks 34a, 34b.

3 The leading and trailing modules 26, 28 may be fixed with respect to one another in  
4 order to maintain alignment of read and write elements 36, 38 contained thereon.  
5 Nevertheless, the recording head 14 as a whole may be translated with respect to the tape 12  
6 in order to align read and write elements 36, 38 with the data tracks 32. In certain  
7 embodiments, the leading and trailing modules 26, 28 are glued or welded together, or are  
8 constructed from a single piece of material.

9 Referring to Figure 3A, the leading and trailing modules 26, 28 may be provided in  
10 various configurations. For example, in selected embodiments, the read and write elements  
11 36a-d, 38a-d are provided in a "piggyback" configuration 42. That is, read elements 36 and  
12 write elements 38 are substantially aligned with one another with respect to a tape 12 passing  
13 thereby. In this configuration 42, data written by a write element 38a, on a leading module  
14 26, may be read by a read element 36c on the trailing module 28. Likewise, if a tape 12 is  
15 traveling in the opposite direction, data written by a write element 38c, on a leading module  
16 28, may be read by a read element 36a on a trailing module 26.

17 As described previously, tape 12 may shrink or expand due to temperature, humidity,  
18 creep, and other causes. In such cases, it may be advantageous to offset 44 the leading and  
19 trailing modules 26, 28 by a select distance 44. This offset 44 enables more precise centering  
20 of read and write elements 36, 38 over the data tracks 32. Selected read and write elements  
21 36, 38 are used from one module 26, 28, while other read and write elements 36, 38 are used  
22 from the other module 26, 28.

23 Referring to the enlarged view 46, the offset 44 may be selected such that a read  
24 element 36 on the trailing module 28 still accurately reads data written by a write element 38  
25 on the leading module 26. For example, if a write element 38 writes data to a track 32, the  
26 read element 36 is still aligned within the boundaries of the track 32, thereby enabling a  
27 successful read.

1 Referring to Figure 3B, in another embodiment, the read and write elements 36a-d,  
2 38a-d are provided in an "interleaved" configuration 48. That is, read elements 36 and write  
3 elements 38 are alternated along the length of each of the modules 26, 28. A leading module  
4 26 is an inverted image of the trailing module 28, meaning that a read element 36a on the  
5 leading module 26 is aligned with a write element 38c on a trailing module, and vice versa.  
6 Data written by a write element 38a, on a leading module 26, may be read by a read element  
7 36c on the trailing module 28. Likewise, if a tape 12 is traveling in the opposite direction,  
8 data written by a write element 38c, on a leading module 28, may be read by a read element  
9 36a on a trailing module 26.

10 As in the previous example illustrated in Figure 3A, the leading and trailing modules  
11 26, 28 are offset by a select distance 44 to enable more precise centering of read and write  
12 elements 36, 38 over the data tracks 32 to compensate for tape 12 shrinkage or expansion.  
13 Select read and write elements 36, 38 are used from one module 26, 28, while other read and  
14 write elements 36, 38 are used from the other module 36, 38.

15 Referring to the enlarged view 50, the offset 44 may be selected such that a read  
16 element 36 on the trailing module 28 still accurately reads data written by a write element 38  
17 on the leading module 26. For example, if a write element 38 writes data to a track 32, the  
18 read element 36 is still aligned within the boundaries of the track 32, thereby enabling a  
19 successful read operation.

20 Referring to Figure 4, for simplicity, only read elements 36 are illustrated to  
21 demonstrate the alignment of the read elements 36 with data tracks 32 on the tape 12. For  
22 example, if the dimensions of a tape 12 are substantially unaltered from when the tape was  
23 last written (e.g. not shrunk or expanded), then read elements 36a-h from a single leading or  
24 trailing module 26, 28 may be aligned with the data tracks 32a-h to read data therefrom.  
25 Servo readers 40a, 40b are used to center the leading or trailing module 26 over the data  
26 tracks 32ah by reading the servo tracks 34a, 34b. Thus, read elements 36a-h are aligned with  
27 or centered over the data tracks 32a-h. In this scenario, none of the read elements 36i-p from

1 the module 28 is used to read data from the data tracks 32a-h.

2 Referring to Figure 5, in another embodiment, if the width of the tape 12 has  
3 expanded from the time the tape 12 was last written, in a direction 52, select read elements  
4 36a-d from a leading module 26 are used to read data from selected data tracks 32a-d, while  
5 read elements 36m-p from the trailing module 28 are used to read other selected data tracks  
6 32e-h. Since read elements 36a-h are offset with respect to read elements 36i-p, certain read  
7 elements 36a-d on the leading module 26 are more aligned with data tracks 32a-d than read  
8 elements 36i-l on the trailing module 28. Likewise, certain read elements 36m-p on the  
9 trailing module 28 are more aligned with data tracks 32e-h than other read elements 36e-h on  
10 the leading module 26. Thus, the offset of the trailing module 28 with respect to the leading  
11 module 26 provides for more accurate reading of data from the tape 12.

12 Referring to Figure 6, in certain embodiments, an apparatus and method in  
13 accordance with the invention may be used in tape data storage systems, such as in an LTO  
14 (Linear Tape-Open) system 54. In such a system 54, multiple sets 56 of servo tracks and  
15 multiple sets 58 of data tracks are provided on a tape 12. Servo tracks 56 may include  
16 various reference tracks 59 that are angled with respect to one another. By measuring  
17 selected distances 60 between tracks 59, a servo system effectively aligns a recording head  
18 14 with desired data tracks 58 on the tape 12.

19 In some cases, a set 56a of servo tracks define a plurality of positions of a recording  
20 head 14. For example, in an LTO system 54, a recording head 14 reads or writes eight data  
21 tracks simultaneously. However, sets 56a, 56b of servo tracks can be used to define any  
22 number of positions between the edges of the servo band 56. In LTO systems 54, twelve  
23 different positions of the head 14 are defined, thereby yielding a total of ninety-six data  
24 tracks 58a (12 positions multiplied by 8 data tracks) between servo tracks 56a, 56b. If four  
25 sets of data tracks 58a, 58b, 58c, 58d are provided, a tape 12 may store three hundred and  
26 eighty-four data tracks 58a-d (96 data tracks multiplied by 4 sets).

27 In addition, a recording head 14 may read or write data on the tape 12 in both

1 directions. For example, a recording head 14 may read or write selected tracks 62a, 62c, 62e  
2 in a first direction, and read or write other selected tracks 62b, 62d in a second direction. By  
3 reading and writing in both directions, data may be written and read faster and with more  
4 efficiency.

5 Thus, a tape 12 may be very densely populated with data tracks 58. Under these  
6 circumstances, even a minute amount of tape shrinkage or expansion can cause misalignment  
7 of data tracks with the recording head 14, thereby incurring data loss or corruption. Thus,  
8 apparatus and methods in accordance with the invention enable more accurate storage and  
9 retrieval of data. An LTO system 54 simply represents one example of a system wherein  
10 apparatus and methods in accordance with the invention may be used. In reality, offsetting  
11 the leading and trailing module 26, 28 may be used in any tape system to compensate for tape  
12 shrinkage or expansion.

13 Referring to Figure 7, a recording head 14 having offset leading and trailing modules  
14 26, 28 may be characterized by a plurality of modes. For example, in selected embodiments,  
15 in cases where the dimensions of a tape 12 have expanded since last written, a first mode 64  
16 uses read elements 72 from a first half of a leading module 26, and read elements 74 from a  
17 second half of the trailing module 28.

18 Likewise, in cases where the dimensions of a tape 12 have contracted or shrunk since  
19 last written, a second mode 66 uses read elements 76 from a first half of the trailing module  
20 28, and read elements 78 from a second half of the leading module 26. Similarly, if  
21 dimensions of a tape 12 have neither expanded nor contracted, a third mode 68 comprises  
22 read elements 72, 78 from both halves of a leading module 26. Substantially interchangeable  
23 with the third mode 68, a fourth mode 70 comprises read elements 76, 74 from both halves of  
24 a trailing module 28.

25 By dividing the leading and trailing modules 26, 28 into halves 72, 74, 76, 78, modes  
26 64, 66, 68 corresponding to an expanded, shrunken, or a substantially unaltered state of the  
27 tape 12 are provided.



1 Referring to Figure 8A, in selected embodiments, a control module 88 is used to  
2 toggle between the different modes described with respect to Figure 7. For example, a  
3 control module 88 may adjust and center the recording head 14 over the tape 12. The control  
4 module may also monitor or determine the width of the tape 12.

5 The control module 88 may receive input from servo readers 40a-d to center the  
6 recording head 14 over the tape 12, as well as to determine the width of the tape 12. In  
7 certain embodiments, the width of the tape 12, corresponding to when data was last written,  
8 may actually be read from the tape 12. That is, each time data is written to data tracks 32 on  
9 a tape 12, the width of the tape 12 is recorded or written onto the tape 12 for later retrieval  
10 upon reading of the data, or upon rewriting over the data. The width, when written, may then  
11 be compared to the width, when read, in order to select one of the three modes (e.g. wide,  
12 normal, or narrow) based on the difference.

13 In selected embodiments, another similar but simpler approach is to switch between  
14 the three modes and to choose the one with the smallest error rate. This could be done by  
15 either reading actual data stored on the tape 12 or could be accomplished using a special "test  
16 area" written onto the tape 12. In other embodiments, an apparatus and method in  
17 accordance with the invention could switch between the three modes only upon error  
18 recovery when reading data.

19 If a tape 12 has expanded, the servo readers 40 may sense this state due to their  
20 alignment with the servo tracks 34a, 34b on the tape 12. If expanded, the control module 88  
21 selectively reads data using read elements 72, 74. If the tape 12 has shrunk, the control  
22 module 88 selectively reads data using read elements 76, 78. Likewise, if dimensions of the  
23 tape 12 are substantially unaltered, the control module 88 selects read elements 72, 78 from  
24 the leading module 26, or read elements 76, 74 from the trailing module 28.

25 Referring to Figure 8B, the control module 88 need not read data from halves 72, 74,  
26 76, 78 of the leading and trailing modules 26, 28, as illustrated in Figure 8A. The control  
27 module may select read elements 36 that best align with the data tracks 32 as needed. This

1 can be used advantageously where the expansion of the tape 12 is not uniform between the  
2 servo readers 40a, 40b. Data for determining which read elements 36a-p to select could  
3 come from monitoring signals from the read elements 36a-p as the head 14 is moved slightly  
4 back and forth over the tracks 32 in regions along the tape 12 written expressly for that  
5 purpose.

6 For example, in one contemplated embodiment, the control module 88 dynamically  
7 selects specific read elements 36a-p to read data from a tape 12. Various read elements 36a-  
8 h are used from the leading module 26, while others 36i-p are used from the trailing module  
9 28. The read elements 36 may be selected in any combination, as needed, and may be those  
10 that best align with data tracks 32 present on the tape 12. The control module 88 may also  
11 optimize centering of the leading and trailing modules 26, 28 over the data tracks 32 using  
12 the servo readers 40a-d.

13 Referring to Figure 9, the distance 44 the trailing module 28 is shifted with respect to  
14 the leading module 26 is important since the offset 44 may be fixed at the time of  
15 manufacture of the head 14. The operating environment may set limits on the amount the  
16 tape 12 can expand or contract between outer elements 36a, 36p of the read head 14 and still  
17 remain operable. For example, if the limit for tape expansion is 2 microns between the outer  
18 two data tracks 32a, 32h, as is illustrated in this example, and where one is reading over half  
19 of the head 14 width, as enabled by this disclosure, the servos 40 can center the read  
20 elements 36 such that the worst-case misalignment is 0.43 micron if the shift 44 between  
21 modules is 1.14 microns.

22 In selected embodiments, an optimum offset 44 between the leading and trailing  
23 modules 26, 28 may be calculated to be approximately 57% of the maximum amount of  
24 shrinkage or expansion of a tape 12. That is, if it is determined that a tape 12 may shrink or  
25 expand by a maximum of 2 microns, the optimum offset 44 for the leading and trailing  
26 modules 26, 28 may be 1.14 microns. Nevertheless, any nonzero offset 44 between the  
27 leading and trailing modules 26, 28 is within the scope of the present invention.

1           The present invention may be embodied in other specific forms without departing  
2 from its essence or essential characteristics. The described embodiments are to be  
3 considered in all respects only as illustrative, and not restrictive. The scope of the invention  
4 is, therefore, indicated by the appended claims, rather than by the foregoing description. All  
5 changes within the meaning and range of equivalency of the claims are to be embraced  
6 within their scope.

7           What is claimed and desired to be secured by United States Letters Patent is:  
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